

TITLE OF THE INVENTION

[0001] LOW VOLTAGE MODULAR ROOM IONIZATION SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

- [0002] This application is a continuation of copending Application No. 10/299,499 filed
5 November 19, 2002 entitled "LOW VOLTAGE MODULAR ROOM IONIZATION SYSTEM,"
which is a continuation of Application No. 10/024,861 filed December 18, 2001 entitled "LOW
VOLTAGE MODULAR ROOM IONIZATION SYSTEM," which is a continuation of copending
Application No. 09/852,248 filed May 9, 2001 entitled "CIRCUIT FOR AUTOMATICALLY
10 INVERTING ELECTRICAL LINES CONNECTED TO A DEVICE UPON DETECTION OF A
MISWIRED CONDITION TO ALLOW FOR OPERATION OF DEVICE EVEN IF MISWIRED,"
now U.S. Patent No. 6,417,581, which is a continuation of copending Application No. 09/287,935
filed April 7, 1999 entitled "LOW VOLTAGE MODULAR ROOM IONIZATION SYSTEM," now
U.S. Patent No. 6,252,756, the entire disclosure of all three copending applications incorporated
herein by reference.
- 15 [0003] This application claims the benefit of U.S. Provisional Application No. 60/101,018 filed
Sep. 18, 1998 entitled "LOW VOLTAGE MODULAR ROOM IONIZATION SYSTEM."

BACKGROUND OF THE INVENTION

- [0004] Controlling static charge is an important issue in semiconductor manufacturing because
of its significant impact on the device yields. Device defects caused by electrostatically attracted
20 foreign matter and electrostatic discharge events contribute greatly to overall manufacturing losses.
- [0005] Many of the processes for producing integrated circuits use non-conductive materials
which generate large static charges and complimentary voltage on wafers and devices.
- [0006] Air ionization is the most effective method of eliminating static charges on
non-conductive materials and isolated conductors. Air ionizers generate large quantities of positive
25 and negative ions in the surrounding atmosphere which serve as mobile carriers of charge in the air.
As ions flow through the air, they are attracted to oppositely charged particles and surfaces.
Neutralization of electrostatically charged surfaces can be rapidly achieved through the process.
- [0007] Air ionization may be performed using electrical ionizers which generate ions in a
process known as corona discharge. Electrical ionizers generate air ions through this process by

intensifying an electric field around a sharp point until it overcomes the dielectric strength of the surrounding air. Negative corona occurs when electrons are flowing from the electrode into the surrounding air. Positive corona occurs as a result of the flow of electrons from the air molecules into the electrode.

5 [0008] To achieve the maximum possible reduction in static charges from an ionizer of a given output, the ionizer must produce equal amounts of positive and negative ions. That is, the output of the ionizer must be "balanced." If the ionizer is out of balance, the isolated conductor and insulators can become charged such that the ionizer creates more problems than it solves. Ionizers may become imbalanced due to power supply drift, power supply failure of one polarity, contamination
10 of electrodes, or degradation of electrodes. In addition, the output of an ionizer may be balanced, but the total ion output may drop below its desired level due to system component degradation.

[0009] Accordingly, ionization systems incorporate monitoring, automatic balancing via feedback systems, and alarms for detecting uncorrected imbalances and out-of-range outputs. Most feedback systems are entirely or primarily hardware-based. Many of these feedback systems cannot
15 provide very fine balance control, since feedback control signals are fixed based upon hardware component values. Furthermore, the overall range of balance control of such hardware-based feedback systems may be limited based upon the hardware component values. Also, many of the hardware-based feedback systems cannot be easily modified since the individual components are dependent upon each other for proper operation.

20 [0010] A charged plate monitor is typically used to calibrate and periodically measure the actual balance of an electrical ionizer, since the actual balance in the work space may be different from the balance detected by the ionizer's sensor.

[0011] The charged plate monitor is also used to periodically measure static charge decay time. If the decay time is too slow or too fast, the ion output may be adjusted by increasing or decreasing
25 the preset ion current value. This adjustment is typically performed by adjusting two trim potentiometers (one for positive ion generation and one for negative ion generation). Periodic decay time measurements are necessary because actual ion output in the work space may not necessarily correlate with the expected ion output for the ion output current value set in the ionizer. For example, the ion output current may be initially set at the factory to a value (e.g., 0.6 μA) so as to
30 produce the desired amount of ions per unit time. If the current of a particular ionizer deviates from this value, such as a decrease from this value due to particle buildup on the emitter of the ionizer, then the ionizer high voltage power supply is adjusted to restore the initial value of ion current.

[0012] A room ionization system typically includes a plurality of electrical ionizers connected to a single controller. Fig. 1 (prior art) shows a conventional room ionization system **10** which includes a plurality of ceiling-mounted emitter modules **12₁-12_n** (also, referred to as "pods") connected in a daisy-chain manner by signal lines **14** to a controller **16**. Each emitter module **12** includes an electrical ionizer **18** and communications/control circuitry **20** for performing limited functions, including the following functions:

[0013] (1) TURN ON/OFF;

[0014] (2) send an alarm signal to the controller **16** through a single alarm line within the signal lines **14** if a respective emitter module **12** is detected as not functioning properly.

[0015] One significant problem with the conventional system of Fig. 1 is that there is no "intelligent" communication between the controller **16** and the emitter modules **12₁-12_n**. In one conventional scheme, the signal line **14** has four lines; power, ground, alarm and ON/OFF control. The alarm signal which is transmitted on the alarm line does not include any information regarding the identification of the malfunctioning emitter module **12**. Thus, the controller **16** does not know which emitter module **12** has malfunctioned when an alarm signal is received. Also, the alarm signal does not identify the type of problem (e.g., bad negative or positive emitter, balance off). Thus, the process of identifying which emitter module **12** sent the alarm signal and what type of problem exists is time-consuming.

[0016] Yet another problem with conventional room ionization systems is that there is no ability to remotely adjust parameters of the individual emitter modules **12**, such as the ion output current or balance from the controller **16**. These parameters are typically adjusted by manually varying settings via analog trim potentiometers on the individual emitter modules **12**. (The balances on some types of electrical ionizers are adjusted by pressing (+)/(-) or UP/DOWN buttons which control digital potentiometer settings.) A typical adjustment session for the conventional system **10** having ceiling mounted emitter modules **12** is as follows:

[0017] (1) Detect an out-of-range parameter via a charged plate monitor;

[0018] (2) Climb up on a ladder and adjust balance and/or ion output current potentiometer settings;

[0019] (3) Climb down from the ladder and remove the ladder from the measurement area.

[0020] (4) Read the new values on the charged plate monitor;

[0021] (5) Repeat steps (1)-(4), if necessary.

[0022] The manual adjustment process is time-consuming and intrusive. Also, the physical presence of the operator in the room interferes with the charge plate readings.

[0023] Referring again to Fig. 1, the signal lines **14** between respective emitter modules **12** consist of a plurality of wires with connectors crimped, soldered, or otherwise attached, at each end.

5 The connectors are attached in the field (i.e., during installation) since the length of the signal line **14** may vary between emitter modules **12**. That is, the length of the signal line **14** between emitter module **12₁** and **12₂** may be different from the length of the signal line **14** between emitter module **12₃** and **12₄**. By attaching the connectors in the field, the signal lines **14** may be set to exactly the right length, thereby resulting in a cleaner installation.

10 [0024] One problem which occurs when attaching connectors in the field is that the connectors are sometimes put on backwards. The mistake may not be detected until the entire system is turned on. The installer must then determine which connector is on backwards and must fix the problem by rewiring the connector.

[0025] The conventional room ionization system **10** may be either a high voltage or low voltage system. In a high voltage system, a high voltage is generated at the controller **16** and is distributed via power cables to the plurality of emitter modules **12** for connection to the positive and negative emitters. In a low voltage system, a low voltage is generated at the controller **16** and is distributed to the plurality of emitter modules **12** where the voltage is stepped up to the desired high voltage for connection to the positive and negative emitters. In either system, the voltage may be AC or DC. If
20 the voltage is DC, it may be either steady state DC or pulse DC. Each type of voltage has advantages and disadvantages.

[0026] One deficiency of the conventional system **10** is that all emitter modules **12** must operate in the same mode. Thus, in a low voltage DC system, all of the emitter modules **12** must use steady state ionizers or pulse ionizers.

25 [0027] Another deficiency in the conventional low voltage DC system **10** is that a linear regulator is typically used for the emitter-based low voltage power supply. Since the current passing through a linear regulator is the same as the current at its output, a large voltage drop across the linear regulator (e.g., 25 V drop caused by 30 V in/5 V out) causes the linear regulator to draw a significant amount of power, which, in turn, generates a significant amount of heat. Potential
30 overheating of the linear regulator thus limits the input voltage, which in turn, limits the amount of emitter modules that can be connected to a single controller **16**. Also, since the power lines are not lossless, any current in the line causes a voltage drop across the line. The net effect is that when

linear regulators are used in the emitter modules **12**, the distances between successive daisy-chained emitter modules **12**, and the distance between the controller **16** and the emitter modules **12** must be limited to ensure that all emitter modules **12** receive sufficient voltage to drive the module-based high voltage power supplies.

5 [0028] Accordingly, there is an unmet need for a room ionization system which allows for improved flexibility and control of, and communication with, emitter modules. There is also an unmet need for a scheme which automatically detects and corrects the miswire problem in an easier manner. There is also an unmet need for a scheme which allows individualized control of the modes of the emitter modules. The present invention fulfills these needs.

BRIEF SUMMARY OF THE INVENTION

[0029] Methods and devices are provided for balancing positive and negative ion output in an electrical ionizer having positive and negative ion emitters and positive and negative high voltage power supplies associated with the respective positive and negative ion emitters. A balance reference value is stored in a software-adjustable memory. During operation of the electrical ionizer, the balance reference value is compared to a balance measurement value. At least one of the positive and negative high voltage power supplies are automatically adjusted if the balance reference value is not equal to the balance measurement value. The adjustment is performed in a manner which causes the balance measurement value to become equal to the balance reference value. Also, during a calibration or initial setup of the electrical ionizer, the actual ion balance is measured in the work space near the electrical ionizer using a charged plate monitor. The balance reference value is adjusted if the actual balance measurement shows that the automatic ion balance scheme is not providing a true balanced condition.

[0030] The balance reference value may be adjusted by a remote control device or by a system controller connected to the electrical ionizer.

25 **[0031]** The present invention also provides an ionization system for a predefined area comprising a plurality of emitter modules spaced around the area, a system controller for monitoring and/or controlling the emitter modules, and a communication medium or electrical lines which electrically connect the plurality of emitter modules with the system controller.

[0032] In one embodiment of the ionization system, each emitter module has an individual address and the system controller individually addresses and controls each emitter module. The balance reference value and an ion output current reference value of each emitter module may be individually adjusted, either by the system controller or by a remote control transmitter.

[0033] In another embodiment of the ionization system, each emitter module is provided with a switching power supply to minimize the effects of line loss on the electrical lines.

[0034] In another embodiment of the ionization system, a power mode setting is provided for setting each emitter module in one of a plurality of different operating power modes.

5 **[0035]** The present invention also comprises a method of balancing positive and negative ion output in an electrical ionizer having positive and negative ion emitters and positive and negative high voltage power supplies associated with the respective positive and negative ion emitters. The method includes storing a balance reference value in a software-adjustable memory located in the electrical ionizer, comparing the balance reference value to a balance measurement value during
10 operation of the electrical ionizer, and automatically adjusting at least one of the positive and negative high voltage power supplies if the balance reference value is not equal to the balance measurement value by ramping up or ramping down the at least one of the positive and negative power supplies at a first predetermined rate. The adjustment is performed in a manner which causes the balance measurement value to become equal to the balance reference value.

15 **[0036]** The present invention also comprises an electrical ionizer having positive and negative ion emitters and positive and negative high voltage power supplies associated with the respective positive and negative ion emitters. The electrical ionizer includes a software-adjustable memory for storing a balance reference value and a comparator for comparing the balance reference value to a balance measurement value, and an automatic balance adjustment circuit for adjusting at least one of
20 the positive and negative high voltage power supplies if the balance reference value is not equal to the balance measurement value. The adjustment is performed in a manner which causes the balance measurement value to become equal to the balance reference value. The adjustment circuit is configured to ramp up or ramp down the at least one of the positive and negative power supplies at a first predetermined rate.

25 **[0037]** The present invention also comprises a method of balancing positive and negative ion output in an electrical ionizer having positive and negative ion emitters and positive and negative high voltage power supplies associated with the respective positive and negative ion emitters. The electrical ionizer includes receiver circuitry for receiving adjustments to at least one ionizer reference value. The method includes storing a balance reference value in a software-adjustable
30 memory, comparing the balance reference value to a balance measurement value during operation of the electrical ionizer, automatically adjusting at least one of the positive and negative high voltage power supplies if the balance reference value is not equal to the balance measurement value by

ramping up or ramping down the at least one of the positive and negative power supplies at a predetermined rate. The adjustment being performed in a manner which causes the balance measurement value to become equal to the balance reference value. The method also includes measuring the actual ion balance in the work space near the electrical ionizer during operation of the electrical ionizer and adjusting the balance reference value if the balance measurement value is equal to the balance reference value and the actual measured ion balance is not zero. The adjustment is performed in a manner which causes the actual measured ion balance to become equal to zero. The adjustment is performed by communicating the adjustment value to the receiver circuitry of the electrical ionizer, which, in turn, communicates the adjustment value to the software-adjustable memory.

[0038] The present invention also comprises an electrical ionizer having positive and negative ion emitters and positive and negative high voltage power supplies associated with the respective positive and negative ion emitters. The electrical ionizer includes receiver circuitry for receiving adjustments to at least one ionizer reference value, including a balance reference value stored in a software-adjustable memory, a comparator for comparing the balance reference value to a balance measurement value, an automatic balance adjustment circuit for adjusting at least one of the positive and negative high voltage power supplies if the balance reference value is not equal to the balance measurement value. The adjustment is performed in a manner which causes the balance measurement value to become equal to the balance reference value. The adjustment circuit is configured to ramp up or ramp down the at least one of the positive and negative power supplies at a predetermined rate. The electrical ionizer also includes means in communication with the receiver circuitry for adjusting the balance reference value. The balance reference value is adjusted if the balance measurement value is equal to the balance reference value and an actual measured ion balance measured in the work space near the electrical ionizer is not zero. The adjustment is performed in a manner which causes the actual measured ion balance to become equal to zero.

[0039] The present invention also comprises a method of balancing positive and negative ion output in an electrical ionizer having positive and negative ion emitters and positive and negative high voltage power supplies associated with the respective positive and negative ion emitters. The method includes storing a balance reference value in a software-adjustable memory located in the electrical ionizer and ramping up the output of at least one of the positive and negative high voltage power supplies at predetermined rate upon initiation of the operation of the electrical ionizer, thereby avoiding sudden changes in positive or negative ion output or potential overshoot of the

balanced state. the method also includes comparing the balance reference value to a balance measurement value during operation of the electrical ionizer and automatically adjusting at least one of the positive and negative high voltage power supplies if the balance reference value is not equal to the balance measurement value. The adjustment is performed in a manner which causes the balance measurement value to become equal to the balance reference value.

[0040] The present invention also comprises an electrical ionizer having positive and negative ion emitters and positive and negative high voltage power supplies associated with the respective positive and negative ion emitters. The electrical ionizer includes a software-adjustable memory for storing a balance reference value, a comparator for comparing the balance reference value to a balance measurement value, and an automatic balance adjustment circuit for adjusting at least one of the positive and negative high voltage power supplies if the balance reference value is not equal to the balance measurement value. The adjustment is performed in a manner which causes the balance measurement value to become equal to the balance reference value. The adjustment circuit being configured to ramp up the output of at least one of the positive and negative power supplies at a predetermined rate upon initiation of the operation of the electrical ionizer, thereby avoiding sudden changes in positive or negative ion output or potential overshoot of the balanced state.

[0041] The present invention also comprises a method of balancing positive and negative ion output in an electrical ionizer having positive and negative ion emitters and positive and negative high voltage power supplies associated with the respective positive and negative ion emitters. The method includes automatically adjusting at least one of the positive and negative high voltage power supplies by ramping up or ramping down the at least one of the positive and negative power supplies at a predetermined rate.

[0042] The present invention also comprises a method of balancing positive and negative ion output in an electrical ionizer having positive and negative ion emitters and positive and negative high voltage power supplies associated with the respective positive and negative ion emitters. The method includes automatically adjusting at least one of the positive and negative high voltage power supplies by ramping up the at least one of the positive and negative power supplies at a predetermined rate upon initiation of the operation of the electrical ionizer.

[0043] The present invention also comprises an electrical ionizer having positive and negative ion emitters and positive and negative high voltage power supplies associated with the respective positive and negative ion emitters. The electrical ionizer includes an automatic balance adjustment circuit for adjusting at least one of the positive and negative high voltage power supplies, the

adjustment circuit being configured to ramp up the output of at least one of the positive and negative power supplies at a predetermined startup rate upon initiation of the operation of the electrical ionizer, thereby avoiding sudden changes in positive or negative ion output or potential overshoot of the balanced state.

5 [0044] The present invention also comprises a method of balancing positive and negative ion output in an electrical ionizer having positive and negative ion emitters and positive and negative high voltage power supplies associated with the respective positive and negative ion emitters. The method includes automatically adjusting at least one of the positive and negative high voltage power supplies by ramping down the at least one of the positive and negative power supplies at a
10 predetermined rate upon termination of the operation of the electrical ionizer.

[0045] The present invention also comprises an electrical ionizer having positive and negative ion emitters and positive and negative high voltage power supplies associated with the respective positive and negative ion emitters. The electrical ionizer includes an automatic balance adjustment circuit for adjusting at least one of the positive and negative high voltage power supplies, the
15 adjustment circuit being configured to ramp down the output of at least one of the positive and negative power supplies at a predetermined rate upon termination of the operation of the electrical ionizer, thereby avoiding sudden changes in positive or negative ion output or potential overshoot of the balanced state.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

20 [0046] The following detailed description of preferred embodiments of the present invention would be better understood when read in conjunction with the appended drawings. For the purpose of illustrating the present invention, there is shown in the drawings embodiments which are presently preferred. However, the present invention is not limited to the precise arrangements and instrumentalities shown. In the drawings:

25 [0047] Fig. 1 is a prior art schematic block diagram of a conventional room ionization system;

[0048] Fig. 2 is a schematic block diagram of a room ionization system in accordance with the present invention;

[0049] Fig. 3A is a schematic block diagram of an infrared (IR) remote control transmitter circuit for the room ionization system of Fig. 2;

30 [0050] Figs. 3B-1 and 3B-2, taken together (hereafter, referred to as "Fig. 3B"), are a detailed circuit level diagram of Fig. 3A;

[0051] Fig. 4 is a schematic block diagram of an emitter module for the room ionization system of Fig. 2;

[0052] Fig. 5 is a circuit level diagram of a miswire protection circuit associated with Fig. 4;

[0053] Fig. 6 is a schematic block diagram of a system controller for the room ionization system of Fig. 2;

[0054] Fig. 7A is a schematic block diagram of a balance control scheme for the emitter module of Fig. 4;

[0055] Fig. 7B is a schematic block diagram of a current control scheme for the emitter module of Fig. 4;

[0056] Fig. 8 is a perspective view of the hardware components of the system of Fig. 2;

[0057] Figs. 9 is a flowchart of the software associated with a microcontroller of the emitter module of Fig. 4; and

[0058] Fig. 10 is a flowchart of the software associated with a microcontroller of the system controller of Fig. 6.

DETAILED DESCRIPTION OF THE INVENTION

[0059] Certain terminology is used herein for convenience only and is not to be taken as a limitation on the present invention. In the drawings, the same reference letters are employed for designating the same elements throughout the several figures.

[0060] Fig. 2 is a modular room ionization system **22** in accordance with the present invention.

The system **22** includes a plurality of ceiling-mounted emitter modules **24₁-24_n** connected in a daisy-chain manner by RS-485 communication/power lines **26** to a system controller **28**. In one embodiment of the present invention, a maximum of ten emitter modules **24** are daisy-chained to a single system controller **28**, and successive emitter modules **24** are about 7-12 feet apart from each other. Each emitter module **24** includes an electrical ionizer and communications/control circuitry, both of which are illustrated in more detail in Fig. 4. The system **22** also includes an infrared (IR) remote control transmitter **30** for sending commands to the emitter modules **24**. The circuitry of the transmitter **30** is shown in more detail in Figs. 3A and 3B. The circuitry of the system controller **28** is shown in more detail in Fig. 6.

[0061] The system **22** provides improved capabilities over conventional systems, such as shown in Fig. 1. Some of the improved capabilities are as follows:

[0062] (1) Both balance and ion output of each emitter module **24** can be individually adjusted. Each emitter module **24** may be individually addressed via the remote control transmitter **30** or

through the system controller **28** to perform such adjustments. Instead of using analog-type trim potentiometers, the emitter module **24** uses a digital or electronic potentiometer or a D/A converter. The balance and ion current values are stored in a memory location in the emitter module and are adjusted via software control. The balance value (which is related to a voltage value) is stored in memory as B_{REF} , and the ion current is stored in memory as C_{REF} .

[0063] (2) The balance and ion output adjustments may be performed via remote control. Thus, individual emitter modules **24** may be adjusted while the user is standing outside of the "keep out" zone during calibration and setup, while standing close enough to read the charged plate monitor.

[0064] (3) The emitter modules **24** send identification information and detailed alarm condition information to the system controller **28** so that diagnosis and correction of problems occur easier and faster than in conventional systems. For example, the emitter module **24**₃ may send an alarm signal to the system controller **28** stating that the negative emitter is bad, the positive emitter is bad, or that the balance is off.

[0065] (4) A miswire protection circuitry built into each emitter module **24** allows for the installer to flip or reverse the RS-485 communication/power lines **26**. The circuitry corrects itself if the lines are reversed, thereby eliminating any need to rewire the lines. In conventional signal lines, no communications or power delivery can occur if the lines are reversed.

[0066] (5) The mode of each emitter module **24** may be individually set. Thus, some emitter modules **24** may operate in a steady state DC mode, whereas other emitter modules **24** may operate in a pulse DC mode.

[0067] (6) A switching power supply (i.e., switching regulator) is used in the emitter modules **24** instead of a linear regulator. The switching power supply lessens the effects of line loss, thereby allowing the system controller **28** to distribute an adequate working voltage to emitter modules **24** which may be far apart from each other and/or far apart from the system controller **28**. The switching power supply is more efficient than a linear power supply because it takes off the line only the power that it needs to drive the output. Thus, there is less voltage drop across the communication/power line **26**, compared with a linear power supply. Accordingly, smaller gauge wires may be used. The switching power supply allows emitter modules **24** to be placed further away from each other, and further away from the system controller **28**, than in a conventional low voltage system.

[0068] Specific components of the system **22** are described below.

[0069] Fig. 3A shows a schematic block diagram of the remote control transmitter 30. The transmitter 30 includes two rotary encoding switches 32, four pushbutton switches 34, a 4:2 demultiplexer 36, a serial encoder 38, a frequency modulator 40 and an IR drive circuit 42. The rotary encoder switches 32 are used to produce seven binary data lines that are used to "address" the individual emitter modules 24. The four pushbutton switches 34 are used to connect power to the circuitry and create a signal that passes through the 4:2 demultiplexer 36.

[0070] The 4:2 demultiplexer 36 comprises two 2 input NAND gates and one 4 input NAND gate. Unlike a conventional 4:2 demultiplexer which produces two output signals, the demultiplexer 36 produces three output signals, namely, two data lines and one enable line. The "enable" signal (which is not produced by a conventional 4:2 demultiplexer), is produced when any of the four inputs are pulled low as a result of a pushbutton being depressed. This signal is used to turn on a LED, and to enable the encoder and modulator outputs.

[0071] The seven binary data lines from the rotary encoder switches 32, and the two data lines and the enable line from the demultiplexer 36, are passed to the serial encoder 38 where a serial data stream is produced. The modulator 40 receives the enable line from the demultiplexer 36 and the serial data from the encoder 38, and creates a modulated signal. The modulated signal is then passed to the IR diode driver for transmitting the IR information.

[0072] Fig. 3B is a circuit level diagram of Fig. 3A.

[0073] Fig. 4 shows a schematic block diagram of one emitter module 24. The emitter module 24 performs at least the following three basis functions; produce and monitor ions, communicate with the system controller 28, and receive IR data from the transmitter 30.

[0074] The emitter module 24 produces ions using a closed loop topology including three input paths and two output paths. Two of the three input paths monitor the positive and negative ion current and include a current metering circuit 56 or 58, a multi-input A/D converter 60, and the microcontroller 44. The third input path monitors the ion balance and includes a sensor antenna 66, an amplifier 68, the multi-input A/D converter 60, and the microcontroller 44. The two output paths control the voltage level of the high-voltage power supplies 52 or 54 and include the microcontroller 44, a digital potentiometer (or D/A converter as a substitute therefor), an analog switch, high-voltage power supply 52 or 54, and an output emitter 62 or 64. The digital potentiometer and the analog switch are part of the level control 48 or 50.

[0075] In operation, the microcontroller 44 holds a reference ion output current value, C_{REF} , obtained from the system controller 28. The microcontroller 44 then compares this value with a

measured or actual value, C_{MEAS} , read from the A/D converter **60**. The measured value is obtained by averaging the positive and negative current values. If C_{MEAS} is different than C_{REF} , the microcontroller **44** instructs the digital potentiometers (or D/A's) associated with the positive and negative emitters to increase or decrease their output by the same, or approximately the same,
5 amount. The analog switches of the positive level controls **48, 50** are controlled by the microcontroller **44** which turns them on constantly for steady state DC ionization, or oscillates the switches at varying rates, depending upon the mode of the emitter module. The output signals from the analog switches are then passed to the positive and negative high voltage power supplies **52, 54**. The high voltage power supplies **52, 54** take in the DC signals and produce a high voltage potential
10 on the ionizing emitter points **62, 64**. As noted above, the return path for the high voltage potential is connected to the positive or negative current metering circuits **56, 58**. The current metering circuits **56, 58** amplify the voltage produced when the high voltage supplies **52, 54** draw a current through a resistor. The high voltage return circuits then pass this signal to the A/D converter **60** (which has four inputs for this purpose). When requested by the microcontroller **44**, the A/D
15 converter **60** produces a serial data stream that corresponds to the voltage level produced by the high voltage return circuit. The microcontroller **44** then compares these values with the programmed values and makes adjustments to the digital potentiometers discussed above.

[0076] Ion balance of the emitter module **24** is performed using a sensor antenna **66**, an amplifier **68** (such as one having a gain of 34.2), a level adjuster (not shown), and the A/D converter
20 **60**. The sensor antenna **66** is placed between the positive and negative emitters **62, 64**, such as equidistant therebetween. If there is an imbalance in the emitter module **24**, a charge will build up on the sensor antenna **66**. The built-up charge is amplified by the amplifier **68**. The amplified signal is level shifted to match the input range of the A/D converter **60**, and is then passed to the A/D converter **60** for use by the microcontroller **44**.

25 [0077] A communication circuit disposed between the microcontroller **44** and the system controller **28** includes a miswire protection circuit **70** and a RS-485 encoder/decoder **72**.

[0078] The miswire protection circuit allows the emitter module **24** to function normally even if an installer accidentally inverts (i.e., flips or reverses) the wiring connections when attaching the connectors to the communication/power line **26**. When the emitter module **24** is first powered on,
30 the microcontroller **44** sets two switches on and reads the RS-485 line. From this initial reading, the microcontroller **44** determines if the communication/power line **26** is in an expected state. If the communication/power line **26** is in the expected state and remains in the expected state for a

predetermined period of time, then the communication lines of the communication/power line **26** is not flipped and program in the microcontroller **44** proceeds to the next step. However, if the line is opposite the expected state, then switches associated with the miswire protection circuit **70** are reversed to electronically flip the communication lines of the communication/power line **26** to the correct position. Once the communication/power line **26** is corrected, then the path for the system controller **28** to communicate with the emitter module **24** is operational. A full-wave bridge is provided to automatically orient the incoming power to the proper polarity.

[0079] Fig. 5 is a circuit level diagram of the miswire protection circuit **70**. Reversing switches **74₁** and **74₂** electronically flip the communication line, and full-wave bridge **76** flips the power lines. In one preferred four wire ordering scheme, the two RS-485 communication lines are on the outside, and the two power lines are on the inside.

[0080] Referring again to Fig. 4, when the system controller **28** attempts to communicate with an individual emitter module **24**, the first byte sent is the "address." At this time, the microcontroller **44** in the emitter module **24** needs to retrieve the "address" from the emitter module address circuit.

The "address" of the emitter module is set at the installation by adjustment of two rotary encoder switches **90** located on the emitter module **24**. The microcontroller **44** gets the address from the rotary encoder switches **90** and a serial shift register **92**. The rotary encoder switches **90** provide seven binary data lines to the serial shift register **92**. When needed, the microcontroller **44** shifts in the switch settings serially to determine the "address" and stores this within its memory.

[0081] The emitter module **24** includes an IR receive circuit **94** which includes an IR receiver **96**, an IR decoder **98**, and the two rotary encoder switches **90**. When an infrared signal is received, the IR receiver **96** strips the carrier frequency off and leaves only a serial data stream which is passed to the IR decoder **98**. The IR decoder **98** receives the data and compares the first five data bits with the five most significant data bits on the rotary encoder switches **90**. If these data bits match, the IR decoder **98** produces four parallel data lines and one valid transmission signal which are input into the microcontroller **44**.

[0082] The emitter module **24** also includes a watchdog timer **100** to reset the microcontroller **44** if it gets lost.

[0083] The emitter module **24** further includes a switching power supply **102** which receives between 20-28 VDC from the system controller **28** and creates +12 VDC, +5 VDC, -5 VDC, and ground. As discussed above, a switching power supply was selected because of the need to conserve power due to possible long wire runs which cause large voltage drops.

[0084] Fig. 9 is a self-explanatory flowchart of the software associated with the emitter module's microcontroller 44.

[0085] Fig. 6 is a schematic block diagram of the system controller 28. The system controller 28 performs at least three basic functions; communicate with the emitter modules 24, communicate with an external monitoring computer (not shown), and display data. The system controller 28 communicates with the emitter modules 24 using RS-485 communications 104, and can communicate with the monitoring computer using RS-232 communications 106. The system controller 28 includes a microcontroller 110, which can be a microprocessor. Inputs to the microcontroller 110 include five pushbutton switches 112 and a keyswitch 114. The pushbutton switches 112 are used to scroll through an LCD display 116 and to select and change settings. The keyswitch 114 is used to set the system into a standby, run or setup mode.

[0086] The system controller 28 also includes memory 118 and a watchdog timer 120 for use with the microcontroller 110. A portion of the memory 118 is an EEPROM which stores C_{REF} and B_{REF} for the emitter modules 24, as well as other system configuration information, when power is turned off or is disrupted. The watchdog timer 120 detects if the system controller 28 goes dead, and initiates resetting of itself.

[0087] To address an individual emitter module 24, the system controller 28 further includes two rotary encoder switches 122 and a serial shift register 124 which are similar in operation to the corresponding elements of the emitter module 24.

[0088] During set up of the system 22, each emitter module 24 is set to a unique number via its rotary encoder switches 90. Next, the system controller 28 polls the emitter modules 24₁-24_n to obtain their status-alarm values. In one polling embodiment, the system controller 28 checks the emitter modules 24 to determine if they are numbered in sequence, without any gaps. Through the display 116, the system controller 28 displays its finding and prompts the operator for approval. If a gap is detected, the operator may either renumber the emitter modules 24 and redo the polling, or signal approval of the existing numbering. Once the operator signals approval of the numbering scheme, the system controller 28 stores the emitter module numbers for subsequent operation and control. In an alternative embodiment of the invention, the system controller 28 automatically assigns numbers to the emitter modules 24, thereby avoiding the necessity to set switches at every emitter module 24.

[0089] As discussed above, the remote control transmitter 30 may send commands directly to the emitter modules 24 or may send the commands through the system controller 28. Accordingly, the system controller 28 includes an IR receiver 126 and an IR decoder 128 for this purpose.

[0090] The system controller 28 also includes synchronization links, sync in 130 and sync out

5 132. These links allow a plurality of system controllers 28 to be daisy-chained together in a synchronized manner so that the firing rate and phase of emitter modules 24 associated with a plurality of system controllers 28 may be synchronized with each other. Since only a finite number of emitter modules 24 can be controlled by a single system controller 28, this feature allows many more emitter modules 24 to operate in synchronized manner. In this scheme, one system controller
10 28 acts as the master, and the remaining system controllers 28 act as slave controllers.

[0091] The system controller 28 may optionally include relay indicators 134 for running alarms in a light tower or the like. In this manner, specific alarm conditions can be visually communicated to an operator who may be monitoring a stand-alone system controller 28 or a master system controller 28 having a plurality of slave controllers.

15 [0092] The system controller 28 houses three universal input AC switching power supplies (not shown). These power supplies produce an isolated 28 VDC from any line voltage between 90 and 240 VAC and 50-60 Hz. The 28 VDC (which can vary between 20-30 VDC) is distributed to the remote modules 24 for powering the modules. Also, an onboard switching power supply 136 in the system controller 28 receives the 28 VDC from the universal input AC switching power supply, and
20 creates +12 VDC, +5 VDC, -5 VDC, and ground. A switching power supply is preferred to preserve power.

[0093] Fig. 10 is a self-explanatory flowchart of the software associated with the system controller's microcontroller 110.

[0094] Fig. 7A is a schematic block diagram of a balance control circuit 138 of an emitter
25 module 24₁. An ion balance sensor 140 (which includes an op-amp plus an A/D converter) outputs a balance measurement, B_{MEAS} , taken relatively close to the emitters of the emitter module 24₁. The balance reference value 142 stored in the microcontroller 44, B_{REF1} , is compared to B_{MEAS} in comparator 144. If the values are equal, no adjustment is made to the positive or negative high voltage power supplies 146. If the values are not equal, appropriate adjustments are made to the
30 power supplies 146 until the values become equal. This process occurs continuously and automatically during operation of the emitter module 24₁. During calibration or initial setup, balance readings are taken from a charged plate monitor to obtain an actual balance reading,

B_{ACTUAL} , in the work space near the emitter module **24₁**. If the output of the comparator shows that B_{REF1} equals B_{MEAS} , and if B_{ACTUAL} is zero, then the emitter module **24₁** is balanced and no further action is taken. However, if the output of the comparator shows that B_{REF1} equals B_{MEAS} , and if B_{ACTUAL} is not zero, then the emitter module **24₁** is unbalanced. Accordingly, B_{REF1} is adjusted up or down by using either the remote control transmitter **30** or the system controller **28** until B_{ACTUAL} is brought back to zero. Due to manufacturing tolerances and system degradation over time, each emitter module **24** will thus likely have a different B_{REF} value.

[0095] Fig. 7B is a scheme similar to Fig. 7A which is used for the ion current, as discussed above with respect to C_{REF} and C_{MEAS} . In Fig. 7B, C_{MEAS} is the actual ion output current, as directly measured using the circuit elements **56**, **58** and **60** shown in Fig. 4. Comparator **152** compares C_{REF1} (which is stored in memory **150** in the microcontroller **44**) with C_{MEAS} . If the values are equal, no adjustment is made to the positive or negative high voltage power supplies **146**. If the values are not equal, appropriate adjustments are made to the power supplies **146** until the values become equal. This process occurs continuously and automatically during operation of the emitter module **24₁**.

During calibration or initial setup, decay time readings are taken from a charged plate monitor **148** to obtain an indication of the actual ion output current, C_{MEAS} , in the work space near the emitter module **24₁**. If the decay time is within a desired range, then no further action is taken. However, if the decay time is too slow or too fast, C_{REF1} is adjusted upward or downward by the operator. The comparator **152** will then show a difference between C_{MEAS} and C_{REF1} , and appropriate adjustments are automatically made to the power supplies **146** until these values become equal in the same manner as described above.

[0096] As discussed above, conventional automatic balancing systems have hardware-based feedback systems, and suffer from at least the following problems:

[0097] (1) Such systems cannot provide very fine balance control, since feedback control signals are fixed based upon hardware component values.

[0098] (2) The overall range of balance control is limited based upon the hardware component values.

[0099] (3) Quick and inexpensive modifications are difficult to make, since the individual components are dependent upon each other for proper operation.

[00100] Conventional ion current control circuitry suffers from the same problems. In contrast to conventional systems, the software-based balance and ion current control circuitry of the present invention do not suffer from any of these deficiencies.

[00101] Fig. 8 shows a perspective view of the hardware components of the system 22 of Fig. 2.

[00102] The microcontrollers 44 and 110 allow sophisticated features to be implemented, such as the following features:

[00103] (1) The microprocessor monitors the comparators used for comparing B_{REF} and B_{MEAS} ,

5 and C_{REF} and C_{MEAS} . If the differences are both less than a predetermined value, the emitter module 24 is presumed to be making necessary small adjustments associated with normal operation.

However, if one or both of the differences are greater than a predetermined value at one or more instances of time, the emitter module 24 is presumed to be in need of servicing. In this instance, an alarm is sent to the system controller 28.

10 [00104] (2) Automatic ion generation changes and balance changes for each individual emitter module 24 may be ramped up or ramped down to avoid sudden swings or potential overshoots. For example, when using the pulse DC mode, the pulse rate (i.e., frequency) may be gradually adjusted from a first value to the desired value to achieve the desired ramp up or down effect. When using either the pulse DC mode or the steady-state DC mode, the DC amplitude may be gradually adjusted
15 from a first value to the desired value to achieve the desired ramp up or down effect.

[00105] The scope of the present invention is not limited to the particular implementations set forth above. For example, the communications need not necessarily be via RS-485 or RS-232 communication/power lines. In particular, the miswire protection circuitry may be used with any type of communication/power lines that can be flipped via switches in the manner described above.

20 [00106] It will be appreciated by those skilled in the art that changes could be made to the embodiments described above without departing from the broad inventive concept thereof. It is understood, therefore, that this invention is not limited to the particular embodiments disclosed, but it is intended to cover modifications within the spirit and scope of the present invention as defined by the appended claims.

25 [00107] What is claimed is: